


(19)



Europäisches Patentamt

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Office européen des brevets



(11)EP 0 656 458 B1

(12)

EUROPEAN PATENT SPECIFICATION

- (45) Date of publication and mention of the grant of the patent:  
03.02.1999 Bulletin 1999/05

(51) Int Cl.<sup>6</sup>: E21B 10/56, B23B 27/14,  
B24B 3/60, B24B 37/00
- (21) Application number: 94870183.4
- (22) Date of filing: 22.11.1994

(54) Superhard cutting element having reduced surface roughness

Superhartes Schneideelement mit verringerter Oberflächenrauigkeit

Elément de coupe extra-dur avec une rugosité de surface réduite

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| <div>(30) Priority: 22.11.1993 US 156086</div>                                      |  |
| <div>(43) Date of publication of application:<br/>07.06.1995 Bulletin 1995/23</div> | <div>(56) References cited:</div>  |
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Description

[0001] The present invention relates generally to cutting elements for use with rotary drag bits, and more specifically to superhard cutting elements having an extremely smooth finish on at least a portion of the leading surface or cutting face.

[0002] Superhard cutting elements have been commercially available for over two decades. The typical superhard cutting element employed on rotary drag bits for earth boring comprises a substantially planar polycrystalline diamond compact (PDC) table supported by a metal substrate, typically of sintered tungsten carbide, although other metals and combinations of metals have been employed over the years. The cutting face on the vast majority of commercially available PDC cutting elements is a planar, circular surface. In state of the art PDC cutting elements, the cutting face is typically lapped to a smooth finish.

[0003] In some subterranean formations, PDC cutting elements have been very effective in cutting the formation as the drag bit carrying the cutting elements rotates and the edge of the cutting surface engages the formation. However, in certain formations which fail plastically, such as highly pressured or deep shales, mudstones, siltstone and some limestones, as well as other ductile formations, the formation cutting have a marked tendency to adhere to the leading surface or cutting face of the cutting element.

[0004] When cuttings adhere to the cutting face of a cutting element, they tend to collect and to build up as a mass of cuttings adjacent to the point or line of engagement between the cutting face of the PDC cutting element and the formation, potentially increasing the net effective stress of the formation being cut. This build up of cuttings moves the cutting action away from and ahead of the edge of the PDC cutting element and alters the failure mechanism and location of the cutting phenomenon so that cutting of the formation is actually effected by this built up mass, which obviously is quite dull. Thus, the efficiency of the drag bit is drastically reduced.

[0005] Undesired adhesion of cuttings from subterranean formations being drilled by drag bit PDC cutting elements has long been recognized as a problem in the subterranean drilling art. A number of different approaches have been attempted to facilitate removal of formation cuttings from the cutting face of PDC cutting elements. For example, U.S. Patent No. 4 606 418 to Thompson discloses cutting elements having an aperture in the center thereof which feeds drilling fluid from the interior of the drill bit onto the cutting face to cool the diamond table and to remove formation cuttings. U.S. Patent 4 852 671 to Southland discloses a diamond cutting element which has a passage extending from the support structure of the cutting element to the extreme outermost portion of the cutting element, which is notched in the area in which it engages the formation being cut so that drilling from a plenum on the interior of

the bit can be fed through the support structure and to the edge of the cutting element immediately adjacent the formation. U.S. Patent 4 984 642 to Renard et al. discloses a cutting element having a ridged or grooved cutting face on the diamond table to promote the break-up of cuttings of the formation being drilled or in the case of a machine tool, the material being machined, which enhances their removal from the cutting face. The irregular topography of the cutting face itself assists in preventing balling or clogging of the drag bit by reducing the effective surface or contact area of the cutting faces on the cutting elements, which also reduces the pressure differential of the formation chips being cut. U.S. Patent 5 172 778 to Tibbitts et al., assigned to the assignee of the present application, employs ridged, grooved, stair-step, scalloped, waved and other alternative non-planar cutting surface topographies to permit and promote the access of fluid in the borehole to the area on the cutting element cutting face immediately adjacent to and above the point of engagement with the formation, to equalize differential pressure across the formation chip being cut by the cutting element and thus reduce the shear force which opposes chip movement across the cutting surface. U.S. Patent 4 883 132 to Tibbitts, assigned to the assignee of the present application, discloses a novel drill bit design providing large cavities between the face of the bit and the cutting elements engaging the formation, so that formation cuttings enter the cavity area where they are unsupported and thus more likely to break off for transport up the borehole. Clearing of the cut chips is facilitated by nozzles aimed from behind the cutting elements (taken in the direction of bit rotation) so that the chips are impacted in a forward direction to break off immediately after being cut from the formation. U.S. Patent 4 913 244 to Trujillo, assigned to the assignee of the present invention, discloses bits which employ large cutters having associated therewith directed jets of drilling fluid emanating from specifically oriented nozzles placed in the face of the bit in front of the cutting elements. The jet of drilling fluid is oriented so that the jet impacts between the cutting face of the cutting element and a formation chip as it is moving along the cutting face to peel it away from the cutting element and toward the gage of the bit. U.S. Patent 4 976 324 to Tibbitts, assigned to the assignee of the present invention, discloses diamond-film coated diamond cutting elements of various types such as polycrystalline diamond compact, thermally stable polycrystalline diamond compact (commonly termed TSP's or thermally stable products), Mosaic® cutting elements formed of an array of TSP's, natural diamonds and diamond impregnated cutting elements. The diamond film has a lower porosity or higher purity than the underlying diamond substrate, thus improving the quality, uniformity, and sharpness of the cutting edge of the cutting element, assisting in resisting wear of the cutting element and improving impact resistance of the cutting surface. U.S. Patent 5 115 873 to Pastusek, assigned

to the assignee of the present application, discloses yet another manner in which formation cuttings can be removed from a cutting element by use of a structure adjacent and/or incorporated with the face of the cutting element to direct drilling fluid to the face of the cutting element behind the formation chip as it comes off the formation. U.S. Patent 4 988 421 to Drawl et al. discloses a method of toughening the structure of a diamond or diamond-like coated tool, by depositing by low pressure chemical vapor deposition several layers of diamond or diamond like particles onto a non-diamond or non-diamond-like tool substrate.

[0006] None of the foregoing approaches to cutter and bit design have been completely successful in practice in achieving the desired result of facilitating chip removal from the face of the cutting element. Moreover, it will be appreciated by those skilled in the art that all of the foregoing approaches require significant modification to the cutting elements themselves, to the structure carrying the cutting elements on the bit face, and/or to the bit itself. Thus, all of the foregoing approaches to the problem require significant expenditures and substantially raise the price of the drill bit. In addition, due to required cutter placement on certain styles and sizes of bits, many of the prior art hydraulic chip removal arrangements are unsuitable for general application. Accordingly, it would be extremely desirable to provide the industry with a solution to the impairment of the cutting mechanism caused by chip adhesion, which solution could be economically effected on any drill bit regardless of size or style, and regardless of the type of formation which might be expected to be encountered by the drill bit.

[0007] The above problems are solved by the invention as defined in the appended claims.

[0008] The present invention provides a cutting element including a table of superhard material having a leading surface or cutting face of low or reduced surface roughness in comparison to prior art cutting elements. While the present invention's primary applicability is to polycrystalline diamond compact (PDC) cutting elements having substantially planar diamond tables, the term "substantially planar" is intended and understood to include concave, convex, and other nonlinear diamond table surfaces which nonetheless employ a substantial cutting surface primarily in two dimensions and of any surface shape, topography or geometry, to engage and cut the formation.

[0009] The superhard cutting element according to the present invention is also intended and understood to include variations of polycrystalline diamond compact and other superhard cutting structures. For example, the term "superhard" included without limitation the previously referenced thermally stable products or TSP's, Mosaic® cutting elements formed from TSP's disposed in a planar array, diamond films and cubic boron nitride compacts as well as other superhard materials known in the art.

[0010] The present invention comprises a superhard cutting element having a substantially planar cutting table providing a surface having a cutting edge for engaging a formation to be drilled by the rotary drag bit upon which the cutting element is mounted. The aforementioned surface, which is generally oriented to comprise the leading surface or cutting face of the cutting element, taken in the direction of bit rotation, is processed to a smoothness far in excess of that normally provided in state of the art, commercially available cutting elements.

[0011] In the most preferred embodiment of the present invention, the leading surface or cutting face of the cutting element is mechanically, chemically or otherwise polished substantially to a "mirror" finish in which one can literally see reflections of objects. Reduced perturbation of the polished cutting face lowers the coefficient of friction of the cutting face, and greatly reduces adhesion of the formation chips. In addition, such polishing reduces potential nucleation sites or flaw sites in the cutting face.

[0012] The significant reduction in adhesion reduces the shear stress or resistance to movement of chips on the cutting face, and thus the normal forces as well as tangential forces required for a specified depth of cut in a specific formation. A reduction in normal forces in real-world terms translates to a reduction in the drill string weight required to be applied to the drill bit down hole or an increase in depth of cut and rate of penetration for a given weight on bit, while a reduction in tangential forces translates in real-world terms to a reduction in the torque required to rotate the bit for a given depth of cut and rate of penetration.

[0013] It is also demonstrated that formation chips from formations which fail plastically or which behave in a ductile manner, which are cut by a polished, substantially mirror-finish, superhard cutting element cutting surface under certain drilling conditions, are generally of a substantially uniform thickness and are removed from the formation being drilled in a continuous fashion. This phenomenon is in contrast to the chips cut by a standard superhard cutting element with an unpolished surface under similar conditions, such chips being of irregular configuration and building up in a packed mass on a cutting face of the cutting element to a thickness two to three times the thickness of those on the polished cutting face before moving up the cutting face to the bit face and releasing to be removed up hole. Moreover, the polished cutting elements of the present invention achieve a finely machined "kerf" or bottom hole pattern, and this a smoother borehole bottom, lowering bit vibration and chattering and maintaining more continuous contact between the bit face and the bottom of the borehole.

Fig. 1 is a perspective view of one type of typical superhard cutting element having a substantially planar cutting face;

Fig. 2 is a perspective view of a rotary drag bit hav-

ing PDC cutting elements mounted thereon;  
Fig. 3 is a side elevation of a prior art superhard cutting element as it engages and cuts a subterranean formation, depicting the manner in which formation chips cut from the formation can build up ahead of the cutting face and impede the cutting process and removal of chips from the cutting element;  
Fig. 4 is a side elevation of a superhard cutting element according to the present invention having a polished or mirror finish, depicting the continuous and uniform manner in which a formation chip is cut and removed from the formation without build-up ahead of the cutting face;  
Fig. 5A is an exemplary rendering of a side sectional elevation illustrating the topography of a prior art superhard cutting element cutting face;  
Fig. 5B is an exemplary rendering of a side sectional elevation illustrating the topography of a superhard cutting element cutting face according to the present invention; and  
Figs. 6A-6C are front elevations depicting cutting elements having polished chamfers and sides and partially polished cutting faces, all according to the present invention.

[0014] Referring now to Fig. 1 of the drawings, an exemplary superhard cutting element 10 is depicted in perspective view. Cutting element 10, in this instance a PDC, comprises a diamond table 12 supported on an underlying substrate 14, which is typically of sintered tungsten carbide particles or of any other suitable composition. The boundary between diamond table 12 and substrate 14 may be planar as shown, or may be irregular as illustrated in U.S. Patents 4 784 023, 5 011 515 and 5 120 327 and pending patent application Serial No. 08/016 085 to Smith, assigned to the assignee of the present application and incorporated herein by this reference. The nature or configuration of the boundary between the diamond table 12 and substrate 14 does not, however, form a part of the present invention and so will not be further described.

[0015] In use, as mounted on the rotary drag bit, the superhard cutting element 10 is generally supported by an additional carrier structure such as a cylinder or, as shown in Fig. 1, a so called "stud" 16 having a carrier surface 18 to which the rear surface 20 of substrate 14 is bonded, as by brazing. Stud 16 also includes a free end 22, which is inserted and secured in an aperture drilled or otherwise formed in the face of rotary drag bit to which the superhard cutting element 10 is to be mounted. Alternatively, the carrier structure 16 may comprise a cylinder which is molded into the face of the rotary drag bit when the bit is fabricated, and the superhard cutting element 10 bounded to the end of the cylinder. Both studs and cylinders are typically formed of materials compatible with that of substrate 14, such as the aforementioned tungsten carbide.

[0016] Fig. 2 of the drawings depicts a drill bit 30 having a body 32 secured to a shank 34 having a threaded pin connection 36 thereon, whereby bit 30 is made up to the end of a drill string or to a down hole motor disposed to the end of a drill string. PDC cutting elements 10 are shown secured in a predetermined pattern and at predetermined heights and orientations on the face of the drill bit 30 to provide effective cutting for the formation type to be cut, nozzles 38 on body 32 being positioned to clear chips of formation material leaving cutting elements 10.

[0017] Returning to Fig. 1, the diamond table 12 of PDC cutting element 10 possesses a leading surface face or cutting face 40, the outermost edge 42 of which (as the cutting element 10 is mounted to the body 32 of drill bit 30) may be defined as the cutting edge 42 by which the cutting element 10 engages and cuts the formation. In PDC cutting elements of the prior art, cutting face or leading face 40 of PDC cutting element 10 would typically be lapped to a surface finish of 508-1016 nm (20-40  $\mu$  in.) which is relatively smooth to the touch and visually planar (if the cutting face 40 is itself flat), but which includes a number of surface anomalies and exhibits a degree of roughness which is readily visible to one even under very low power magnification, such as a jeweler's loupe.

[0018] Referring now to Fig. 3 of the drawings, a cutting element 10 is shown mounted on body 32 of a rotary drag bit 30 as bit 30 is inverted from the position shown in Fig. 2 and so oriented for drilling on a subterranean formation. Formation 50, which by way of example may be an aforementioned shale, such as a Catoosa shale, is being engaged by PDC cutting element 10, it being readily seen that the cutting edge 42 is impeded from engaging the pristine or completely uncut portion 52 of formation 50 by virtue of the large build-up of formation cuttings 54 ahead of cutting face 40 and under cutting edge 42. The irregular formation chip 56 which ultimately extends from the build-up 54 on the lower face 40 of cutting element 10 is actually more or less extruded from the massive build-up of formation chips riding against the face 40 of PDC cutting element 10, and not cut directly from the formation 50, so failure of the formation material occurs at area 58.

[0019] It is thus readily apparent that this undesirable build-up of formation material in advance of the PDC cutting elements 10 mounted across the face of the rotary drag bit impair the cutting action of the PDC cutting element 10 as the cutting process is actually effected by this build-up mass of cuttings 54 moved ahead of the actual cutting element 10 itself. As one might imagine, the formation chips are quite dull and cutting is effected in a manner which may be analogized to pushing a dull plow through damp earth, whereby earth is moved out of the way by the mere physical presence, mass and movement of the plow blade surface with an adhered compacted coating of earth, rather than the dirt clods being severed from the underlying earth by a sharp-

edged plow blade. Thus, the normal force, or in real terms the weight on bit 30, which needs to be applied to the bit 30 to affect a desired depth of cut and rate of penetration through the formation 50 must be made undesirably and, in some cases, unreasonably high. In a similar manner the tangential forces of the torque required to rotate the bit 30 at the bottom of the borehole in such a situation is again undesirably increased, as the superhard cutting elements 10 are merely moving the formation chips 56 out of the way by sheer force, being unassisted by the relatively sharp edge 42 of superhard cutting element 10. Stated another way, the required normal and tangential forces are both increased due to the large bearing area provided by the build-up of formation material at the cutting edge of the cutting element 10. The net result is an extremely inefficient rock cutting removal mode, which in some circumstances and in certain formations may actually cause a cessation of drilling.

[0020] Referring now to Fig. 4 of the drawings, a cutting element 10' similar to cutting element 10 is depicted engaging and cutting the same subterranean formation 50. The substantial difference between the two cutting elements is that the cutting face 40 of the superhard cutting element 10' has been physically modified, as by polishing to a mirror finish of 12,7 nm (0,5  $\mu$  in.). As illustrated, it will readily be seen that the cutting edge 42 of cutting element 10' is fully engaged with the pristine or previously uncut and undisturbed area 52 of subterranean formation 50, failure of the formation material occurring immediately adjacent cutting edge 42. Thus, cutting edge 42 is able to cut or shear a formation chip 156 from the formation in an unimpeded manner. As shown, formation chip 156 of substantially uniform thickness moves relatively freely from the point of contact or line of contact from cutting edge 42 of cutting face 40 upwardly along the cutting face 40 until it breaks off either by contact with the body 32 of bit 30 or due to impact by drilling fluid emanating from a nozzle 38 on the face of the bit 32, or fluid coursing through a channel on the face of the drill bit 30. Alternatively, a so-called "chip breaker" as known in the art may be utilized directly above and adjacent cutting face 40 of superhard cutting element 10' for chip 156 to contact and fracture at the point of contact for removal by the drilling fluid to the surface. The polished or mirror finish provided on cutting face 40 of superhard cutting element 10' lowers the overall stresses applied to the rock in the cutting area and permits the chip 156 to ride smoothly due to reduced sliding friction in an unimpeded manner up the cutting face.

[0021] Referring to Figs. 5A and 5B of the drawings, the difference in surface topography between the cutting face 40 of a prior art PDC cutting element 10 and that of a PDC cutting element 10' according to the present invention will be readily appreciated. Figs. 5A and 5B comprise renderings as if a diamond or other superhard table were sectioned perpendicular to the cutting face

40, and not tracings of actual photomicrographs, it being virtually impossible with current techniques to preserve the true surface topography of the diamond table cutting face 40 at a severed edge. In Fig. 5A, cutting face 40 of superhard table 12 of prior art cutting element 10 is shown to contain microscopic "peaks" 100 and "valleys" 102 in the surface 104. Such minute elements may always be present, as well as large "ranges" or "waves" 106 and "canyons" or "troughs" 108 which comprise the major topographic features or perturbations on cutting face 40. It is these ranges or waves 106 and canyons or troughs 108 and not the much smaller microscopic peaks 100 and valleys 102 in surface 104 which provide or result in the 508-1016 nm (20-40  $\mu$  in.) surface roughness of the cutting face 40 of prior art cutting element 10. Fig. 5B, on the other hand, depicts how such waves or ranges 106 are of markedly reduced height and canyons or troughs 108 of markedly reduced depth in the cutting element 10' of the present invention. Broken line 110 provides a reference baseline within each table 12 from which to view the relative surface roughness of cutting element 10 and 10'. Thus, in microscopic terms, the surface smoothing which takes place in producing a cutting element 10 in accordance with the present invention effects a modification and reduction of relatively large-scale features of the surface topography, and not an elimination of individual inclusions in and protrusions from the surface itself. Of course, some significant reduction in potential nucleation sites or flaw sites is achieved, as previously noted.

[0022] It might be expected in the case of the polished or mirror finished cutting face 40 of superhard cutting element 10' that the differential pressure on the outer or leading side 60 of the formation chip 156, the side away from cutting face 40, and that on the inner side 62 on the formation chip 156 immediately abutting the cutting face 40, would cause chip 156 to strongly stick or adhere to the cutting face 40 due to the pressure differential. However, drilling laboratory tests have clearly shown that this is not the case, and that the smoothness and attendant reduced coefficient of friction of cutting face 40 substantially reduces the effect of the phenomenon of differential pressure sticking. Field tests of bits having polished cutting face PDC cutting elements have also confirmed the apparent dominance of the reduction of the coefficient of friction over the increase in differential pressure attributable to the smoothness of the cutting face.

[0023] Single point or single cutter cutting tests in drilling simulators have been performed with PDC cutting elements having standard lapped finish and those which have been polished to a substantially mirror finish. In cutting tests employing General Electric Compax® cutters 9,2 mm square, backraked at an angle of 15°, performed on samples of Catoosa shale under a simulated down hole pressure of 62 MPa (9000 psi) with a 0,127 mm (0,005 inch) depth of cut and a rotational speed of 273 rpm, the mirror finish cutting elements significantly

outperformed the standard lapped finish cutting elements in terms of the force required to achieve a specified depth of cut and rate of penetration.

[0024] For example, in tests performed with these sharp, unchamfered PDC cutting elements, reduction in normal forces (weight on bit) of approximately 60% and reduction in tangential forces (torque) of 35% for the cutter with the polished diamond table were achieved. A second set of comparative single point cutting tests were run with polished and lapped cutting elements having a 0,254 mm (0,010 inch) by 45° chamfer ground on the cutting edge on each cutting element. These tests produced similar results in proportion to those of the first tests with the sharp, unchamfered edges, slight increases in the loads required to cut the formation being experienced due to the chamfered cutting edges of the cutting elements.

[0025] In addition to the relative reduction in normal and tangential loading experienced using polished cutting faces, there was also a marked difference in the appearance of the formation chips and kerf (trough left by the cutting element) produced during the cutting tests. The chips cut by the polished cutting face PDC cutting element were of substantially uniform thickness and substantially continuous appearance. In comparison, the formation chips cut by the standard or unpolished cutting element appear to have convoluted and built up on the cutting face of the cutting element (see Fig. 3) to a thickness two to three times the thickness of those cut by the polished cutting element before breaking loose from the built-up mass and then sliding up the face of the cutter. The kerf cut by the polished cutting element was very smooth, almost machined in uniformity, while the kerf cut by the standard lapped cutting element possessed an irregular profile and bottom surface.

[0026] By way of example and not limitation, the best mode currently known to the inventors for polishing the cutting face 40 of superhard cutting elements 10 to obtain cutting elements 10' of the present invention is lapping of the cutting face on conventional cast iron laps known in the art using progressively smaller diamond grit suspended in a glycol, glycerine or other suitable carrier liquid. The lapping is conducted as a three step process commencing with a 70 nm grit, progressing to a 40 nm grit and then to a grit of about 1-3 nm in size. In contrast, standard lapping techniques for a prior art PDC cutting element 10, which may follow an initial electrodischarge grinding of the cutting face, finish lap in one step with 70 nm grit. By way of comparison of grit size, 70 nm grit is of the consistency of fine sand or crystalline material, while 1-3 nm grit is similar in consistency to powdered sugar.

[0027] It is also contemplated that the cutting element cutting surfaces may be polished by other means, such as ion beams or chemicals, although the inherently inert chemical nature of diamond makes the latter approach somewhat difficult for diamond.

[0028] While an industry-standard PDC or other su-

perhard cutting element typically has a lapped surface finish on the cutting face with irregularities or roughness (measured vertically from the surface) on the order of 508-1016 nm (20-40 μ in.), as a result of the above-described polishing, the most preferred embodiment of the superhard cutting element of the present invention possesses a cutting face surface finish of 7,62 to 12,7 nm (0,3 to 0,5 μ in.) roughness. It appears that a superhard cutting element surface finish with a substantially 254 nm (10 μ in.) roughness provides some of the benefits previously described, although a substantially 50,8 nm (2 μ in.) or less roughness surface finish is more preferred, and a substantially 12,7 nm (0,5 μ in.) or less surface finish roughness approaching a true "mirror" finish is most preferred. The foregoing dimensional irregularities on the cutting face are as measured using a calibrated Hommel America Model T-4000 diamond stylus profilometer contacting the cutting surface of the cutting element.

[0029] To quantify the results achievable by the present invention, when a PDC cutting element is polished to 12,7 nm (0,5 μ in.) mirror finish, calculations based upon force data show the coefficient of friction to be reduced to about half, or fifty percent, of that of a 508-1016 nm (20-40 μ in.) standard finished, but otherwise identical, PDC cutting element. Thus, it can be said that reducing sliding contact stresses between the cutting face and formation chip can be defined macroscopically as achieving a low friction PDC, diamond or other superhard material table.

[0030] It has been proposed in the art (see U.S. Patent 4 976 324) that a diamond film provides a smooth, low friction finish, either alone or as deposited on an underlying substrate, such as a PDC diamond table. However, the inventors have come to recognize that such is not necessarily the case, and that significant reductions in the coefficient of friction of even diamond film surfaces may be achieved by polishing as previously described. This is somewhat unexpected and surprising, since diamond already inherently has the lowest known coefficient of friction of any material. While in some cases the reduction in friction achieved by polishing a diamond film may not be as phenomenal as that noted above with respect to polished versus lapped PDC cutting elements, it is nonetheless substantial and demonstrable.

[0031] Another observed benefit of polishing a superhard cutting element cutting face to a surface finish in the above-referenced beneficial range of 254 nm (10 μ in.) surface finish or finer is the marked reduction in degradation of the cutting face in use. Unlike temporary surface coatings or coverings used in the prior art (see U. S. Patents 5 135 061 and 5 025 874) to protect diamond tables while tripping a bit into the borehole and during the first few minutes of drilling, the polished superhard cutting face of the present invention retains its robust characteristics after many hundreds of feet of drilling.

[0032] While the present invention has been described with reference to individual cutting elements

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mounted at separate locations on a bit face, it is contemplated that the invention has equal utility with blade-type bits wherein very large cutting faces are presented to engage the formation such as those described in the aforementioned U.S. Patent 4 883 132 to Tibbitts and U.S. Patent 4 913 247 to Jones, assigned to the assignee of the present invention and incorporated herein by reference. Such cutting faces may be formed as Mosaic® cutters, or may be fabricated from adjacent round, square or otherwise shaped individual cutting elements of the same or different material, closely spaced and with cooperative or even interlocking borders. As noted previously, convex, concave or other arcuately-surfaced cutting elements may be polished, as may the alternate geometry (stepped, ridged, waved, etc.) cutting element surfaces described in some of the previously-referenced prior art.

[0033] It is also contemplated that sides and chamfers of superhard material tables of cutting elements may be processed to enhanced smoothness according to the present invention, and that the benefits observed from polished cutting faces will be further amplified. Figs. 6A-6C of the drawings depict cutting elements 10' according to the present invention in which the chamfer 24 and side surface 26 of the diamond table have been polished, at least in the portion of the cutting element periphery which will engage the formation. Figs. 6A-6C also illustrate an embodiment of the invention wherein only a segment or portion 140 of cutting face 40 has been smoothed or polished. When only a portion 140 of the cutting face 40, side 26 or chamfer 24 is polished, polishing time may be reduced and the unpolished portion of the cutting face 40 may act as a chip breaker when the formation chip encounters the unpolished area of substantially greater frictional coefficient.

[0034] It is further contemplated that cutting element mounting structures and high erosion- and abrasion-susceptible areas on the bit body, such as waterways 70 and junk slots 72 as illustrated in Fig. 2 of the drawings, may also benefit in terms of integrity and longevity from polishing to an extremely fine surface finish.

[0035] While the present invention has been described in terms of certain preferred embodiments, it is not so limited, and those of ordinary skill in the art will readily recognize and appreciate that many additions, deletions and modifications to the embodiments described herein may be made without departing from the scope of the invention as hereinafter claimed.

Claims

1. A cutting element (10') for drilling subterranean formations, comprising a mass of superhard material defining a substantially planar cutting face (40), characterized in that at least a portion (140) of said cutting face (40) has been polished to a surface finish of substantially 254 nm (10 μin.) or less rough-

ness.

- 2. A cutting element (10') according to claim 1, characterized in that said mass of superhard material is a substantially planar table (12).
- 3. A cutting element (10') according to claim 1 or 2, characterized in that said cutting face portion (140) surface finish is 50.8 nm (2 μin.) or less roughness.
- 4. A cutting element (10') according to claim 3, characterized in that said cutting face portion (140) surface finish is 12.7 nm (0.5 μin.) or less roughness.
- 5. A cutting element (10') according to any one of the preceding claims, characterized in that the polished portion (140) of cutting face (40) has been polished by lapping, ion beam machining or chemical polishing.
- 6. A cutting element (10') according to claim 5, characterized in that the polished portion (140) of cutting face (40) has been polished by lapping.
- 7. A cutting element (10') according to any one of the preceding claims, characterized in that said superhard material comprises a material selected from the group comprising PDC, TSP, diamond film and cubic boron nitride compacts.
- 8. A cutting element (10') according to claim 7, characterized in that said superhard material comprises a material selected from the group comprising PDC, TSP and cubic boron nitride compacts.
- 9. A cutting element (10') according to any one of claims 1 to 8, characterized in that it further comprises a substrate (14) supporting said mass of superhard material.
- 10. A cutting element (10') according to any one of the preceding claims, characterized in that said mass of superhard material comprises laterally adjacent segments of superhard material.
- 11. A cutting element (10') according to claim 10, characterized in that said cutting element (10') comprises a blade.
- 12. A cutting element (10') according to any one of the preceding claims, characterized in that said cutting face (40) has a peripheral cutting edge (42), at least a portion of which has been polished to a surface finish of substantially 254 nm (10 μin.) or less roughness.
- 13. A cutting element (10') according to claim 12, characterized in that the surface finish of said peripheral

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- cutting edge portion is 50.8 nm (2  $\mu$ m.) or less roughness.
14. A cutting element (10') according to claim 13, characterized in that the surface finish of said peripheral cutting edge portion is 12.7 nm (0.5  $\mu$ m.) or less roughness. 5
15. A cutting element (10') according to any one of claims 12 to 14, characterized in that the polished portion of cutting edge (42) has been polished by lapping, ion beam machining or chemical polishing. 10
16. A cutting element (10') according to claim 15, characterized in that the polished portion of cutting edge (42) has been polished by lapping. 15
17. A cutting element (10') according to any one of the preceding claims, characterized in that said cutting face (40) has a peripheral cutting edge (42) having a chamfer (24), at least a portion of which has been polished to a surface finish of 254 nm (10  $\mu$ m.) or less roughness. 20
18. A cutting element (10) according to claim 17, characterized in that the surface finish of said chamfer portion is 50.8 nm (2  $\mu$ m.) or less roughness. 25
19. A cutting element (10') according to claim 18, characterized in that the surface finish of said chamfer portion is 12.7 nm (0.5  $\mu$ m.) or less roughness. 30
20. A cutting element (10) according to any one of claims 17 to 19, characterized in that the polished portion of chamfer (24) has been polished by lapping, ion beam machining or chemical polishing. 35
21. A cutting element (10') according to claims 20, characterized in that the polished portion of chamfer (24) has been polished by lapping. 40
22. A rotary drag bit (30) for drilling subterranean formation, comprising:
- a bit body (32) having a shank (34) secured thereto for connection of said rotary drag bit (30) to a drill string; 45
  - a face on said bit body (32);
  - a plurality of superhard cutting elements (10) disposed on said bit body face, 50
- characterized in that  
at least one of said superhard cutting elements (10) is a cutting element (10') according to any one of claims 1 to 21. 55
23. A method for the manufacture of a superhard cutting element (10') for drilling subterranean forma-

- tion, said cutting element (10') comprising a mass of superhard material defining a substantially planar cutting face (40), characterized in that the method comprises polishing at least a portion (140) of said cutting face (40) to a surface finish of substantially 254 nm (10  $\mu$ m.) or less roughness.
24. A method according to claim 23, characterized in that it comprises polishing at least a portion (140) of said cutting face (40) to a surface finish of substantially 50,8 nm (2  $\mu$ m.) or less roughness.
25. A method according to claim 24, characterized in that it comprises polishing at least a portion (140) of said cutting face (40) to a surface finish of 12.7 nm (0.5  $\mu$ m.) or less roughness.
26. A method according to any one of claims 23 to 25, characterized in that the polishing of at least the portion (140) of the cutting face is effected by lapping, ion beam machining or chemical polishing.
27. A method according to claim 26, characterized in that the polishing of at least the portion (140) of the cutting face is effected by lapping.
28. A method of modifying the cutting characteristics of a cutting element (10) for use on a drill bit (30) for drilling subterranean formation, said cutting element (10) possessing a superhard cutting face (40) exhibiting a surface roughness in excess of about 508 nm (20  $\mu$ m.), comprising lapping at least a portion (140) of said cutting face (40) to such an extent that said surface roughness is reduced by at least fifty percent.
29. A method according to either one of claims 27 and 28, characterized in that it comprises lapping the at least the portion (140) of said cutting face (40) with progressively smaller diamond grit.
30. A method for drilling subterranean formations by means of a rotary drill bit, characterized in that the rotary drill bit is a drill bit as defined in claim 22.

Patentansprüche

1. Ein Schneidelement (10') zum Bohren in unterirdischen Formationen, bestehend aus einer Masse superharten Materials, welches eine im wesentlichen planare Schneidfläche (40) definiert, dadurch charakterisiert, daß wenigstens ein Teil (140) der besagten Schneidfläche (40) auf eine Oberflächenrauigkeit von im wesentlichen 254 nm (10  $\mu$ m.) oder weniger poliert wurde.
2. Ein Schneidelement (10') gemäß Anspruch 1, da-

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- durch charakterisiert, daß besagte Masse superharten Materials einen im wesentlichen planaren Tisch (12) bildet.
3. Ein Schneidelement (10') gemäß Anspruch 1 oder 2, dadurch charakterisiert, daß besagter Teil (140) der Schneidfläche eine Oberflächenrauigkeit von 50,8 nm (2 µ in.) oder weniger aufweist. 5
4. Ein Schneidelement (10') gemäß Anspruch 3, dadurch charakterisiert, daß besagter Teil (140) der Schneidfläche eine Oberflächenrauigkeit von 12,7 nm (0,5 µ in.) oder weniger aufweist. 10
5. Ein Schneidelement (10') gemäß jedem der vorhergehenden Ansprüche, dadurch charakterisiert, daß der polierte Teil (140) der Schneidfläche (40) durch Lappen, Ionenstrahlbearbeitung oder durch chemisches Polieren bearbeitet wurde. 15
6. Ein Schneidelement (10') gemäß Anspruch 5, dadurch charakterisiert, daß der polierte Teil (140) der Schneidfläche (40) durch Lappen poliert wurde. 20
7. Ein Schneidelement (10') gemäß jedem der vorhergehenden Ansprüche, dadurch charakterisiert, daß besagtes superhartes Material ein Material aus der Gruppe ist, welche PDC, TSP, Diamantschicht und kubische Bornitridpreßkörper umfaßt. 25
8. Ein Schneidelement (10') gemäß Anspruch 7, dadurch charakterisiert, daß besagtes superhartes Material ein Material aus der Gruppe ist, welche PDC, TSP und kubische Bornitridpreßkörper umfaßt. 30
9. Ein Schneidelement (10') gemäß jedem der Ansprüche 1 bis 8, dadurch charakterisiert, daß es außerdem ein Substrat (14) umfaßt, welches besagte Masse superharten Materials trägt. 35
10. Ein Schneidelement (10') gemäß jedem der vorhergehenden Ansprüche, dadurch charakterisiert, daß besagte Masse superharten Materials nebeneinanderliegende Segmente aus superhartem Material beinhaltet. 40
11. Ein Schneidelement (10') gemäß Anspruch 10, dadurch charakterisiert, daß besagtes Schneidelement (10') ein Messer umfaßt. 45
12. Ein Schneidelement (10') gemäß jedem der vorhergehenden Ansprüche, dadurch charakterisiert, daß besagte Schneidfläche (40) eine periphere Schneidkante (42) hat, von der mindestens ein Teil 55 auf eine Oberflächenrauigkeit von im wesentlichen 254 nm (10 µ in.) oder weniger poliert wurde.
13. Ein Schneidelement (10') gemäß Anspruch 12, dadurch charakterisiert, daß die Oberfläche der besagten peripheren Schneidkante auf 50,8 nm (2 µ in.) oder weniger poliert wurde.
14. Ein Schneidelement (10') gemäß Anspruch 13, dadurch charakterisiert, daß die Oberfläche der besagten peripheren Schneidkante auf 12,7 nm (0,5 µ in.) oder weniger poliert wurde.
15. Ein Schneidelement (10') gemäß jedem der Ansprüche 12 bis 14, dadurch charakterisiert, daß der polierte Teil der Schneidkante (42) durch Lappen, Ionenstrahlbearbeitung oder chemisches Polieren bearbeitet wurde.
16. Ein Schneidelement (10') gemäß Anspruch 15, dadurch charakterisiert, daß der polierte Teil der Schneidkante (42) durch Lappen bearbeitet wurde.
17. Ein Schneidelement (10') gemäß jedem der vorhergehenden Ansprüche, dadurch charakterisiert, daß besagte Schneidfläche (40) eine periphere Schneidkante (42) hat, die mit einer Fase (24) versehen ist, die zumindest teilweise auf eine Oberflächenrauigkeit von 254 nm (10 µ in.) oder weniger poliert wurde.
18. Ein Schneidelement (10') gemäß Anspruch 17, dadurch charakterisiert, daß besagter Teil der Fase auf eine Oberflächenrauigkeit von 50,8 nm (2 µ in.) oder weniger poliert wurde.
19. Ein Schneidelement (10') gemäß Anspruch 18, dadurch charakterisiert, daß besagter Teil der Fase auf eine Oberflächenrauigkeit von 12,7 nm (0,5 µ in.) oder weniger poliert wurde.
20. Ein Schneidelement (10') gemäß jedem der Ansprüche 17 bis 19, dadurch charakterisiert, daß der polierte Teil der Fase (24) durch Lappen, Ionenstrahlbearbeitung oder chemisches Polieren bearbeitet wurde.
21. Ein Schneidelement (10') gemäß Anspruch 20, dadurch charakterisiert, daß der polierte Teil der Fase (24) durch Lappen bearbeitet wurde.
22. Ein rotierender Bohrkopf (30) zum Bohren in unterirdischen Formationen, bestehend aus:
- einem Bohrkopfkörper (32) mit einem daran befestigten Schaft (34) zur Verbindung besagten rotierenden Bohrkopfes (30) mit einem Bohrgestänge;
  - eine Vorderfläche besagten Bohrkopfkörpers (32);
  - mehreren auf die Vorderfläche besagten Bohr-

kopfkörpers aufgetragenen superharten Schneidelementen (10), dadurch charakterisiert, daß

mindestens eines der besagten superharten Schneidelemente (10) ein Schneidelement (10') gemäß einem der Ansprüche 1 bis 21 ist.

- 23. Ein Verfahren zur Herstellung eines superharten Schneidelements (10') zum Bohren in unterirdischen Formationen, wobei besagtes Schneidelement (10') aus einer Masse superharten Materials besteht, das eine im wesentlichen planare Schneidfläche (40) definiert, die dadurch charakterisiert ist, daß das Verfahren das Polieren zumindest eines Teils (140) besagter Schneidfläche (40) auf eine Oberflächenrauigkeit von im wesentlichen 254 nm (10 µin.) oder weniger beinhaltet.
- 24. Ein Verfahren gemäß Anspruch 23, dadurch charakterisiert, daß es das Polieren zumindest eines Teils (140) besagter Schneidfläche (40) auf eine Oberflächenrauigkeit von im wesentlichen 50,8 nm (2 µin.) oder weniger beinhaltet.
- 25. Ein Verfahren gemäß Anspruch 24, dadurch charakterisiert, daß es das Polieren zumindest eines Teils (140) besagter Schneidfläche (40) auf eine Oberflächenrauigkeit von im wesentlichen 12,7 nm (0,5 µin.) oder weniger beinhaltet.
- 26. Ein Verfahren gemäß jedem der Ansprüche 23 bis 25, dadurch charakterisiert, daß das Polieren zumindest eines Teils (140) der Schneidfläche durch Läppen, Ionenstrahlbearbeitung oder chemisches Polieren durchgeführt wird.
- 27. Ein Verfahren gemäß Anspruch 26, dadurch charakterisiert, daß das Polieren zumindest eines Teils (140) der Schneidfläche durch Läppen durchgeführt wird.
- 28. Ein Verfahren zur Modifizierung der Schneideigenschaften eines Schneidelements (10) zur Verwendung an einem Bohrkopf (30) zum Bohren in unterirdischen Formationen, wobei besagtes Schneidelement (10) eine superharte Schneidfläche (40) besitzt, die eine Oberflächenrauigkeit von mehr als ca. 508 nm (20 µin.) aufweist, welches das Läppen zumindest eines Teils (140) besagter Schneidfläche (40) umfaßt, so daß besagte Oberflächenrauigkeit um mindestens 50 Prozent reduziert wird.
- 29. Ein Verfahren gemäß einem der Ansprüche 27 und 28, dadurch charakterisiert, daß es das Läppen zumindest des Teils (140) besagter Schneidfläche (40) mit progressiv feiner werdendem Diamant-

grobstaub umfaßt.

- 30. Ein Verfahren zum Bohren in unterirdischen Formationen mittels eines rotierenden Bohrkopfes, dadurch charakterisiert, daß der rotierende Bohrkopf ein Bohrkopf gemäß Definition in Anspruch 22 ist.

Revendications

- 1. Elément de coupe (10') pour le forage de formations souterraines, comprenant une masse de matériau extra-dur définissant une face de coupe (40) pratiquement plane, caractérisé en ce qu'au moins une partie (140) de ladite face de coupe (40) a été polie jusqu'à un fini de surface d'une rugosité de pratiquement 254 nm (10 micropouces) ou moins.
- 2. Elément de coupe (10') suivant la revendication 1, caractérisé en ce que ladite masse de matériau extra-dur est une table pratiquement plane (12).
- 3. Elément de coupe (10') suivant la revendication 1 ou 2, caractérisé en ce que le fini de surface de ladite partie de face de coupe (140) a une rugosité de 50,8 nm (2 micropouces) ou moins.
- 4. Elément de coupe (10') suivant la revendication 3, caractérisé en ce que le fini de surface de ladite partie de face de coupe (140) a une rugosité de 12,7 nm (0,5 micropouce) ou moins.
- 5. Elément de coupe (10') suivant l'une quelconque des revendications précédentes, caractérisé en ce que la partie polie (140) de la face de coupe (40) a été polie par rodage, usinage par faisceau d'ions ou polissage chimique.
- 6. Elément de coupe (10') suivant la revendication 5, caractérisé en ce que la partie polie (140) de la face de coupe (40) a été polie par rodage.
- 7. Elément de coupe (10') suivant l'une quelconque des revendications précédentes, caractérisé en ce que ledit matériau extra-dur comprend un matériau sélectionné parmi le groupe comprenant des plaquettes de PDC, TSP, film de diamant et nitrure de bore cubique.
- 8. Elément de coupe (10') suivant la revendication 7, caractérisé en ce que ledit matériau extra-dur comprend un matériau sélectionné parmi le groupe comprenant des plaquettes de PDC, TSP et nitrure de bore cubique.
- 9. Elément de coupe (10') suivant l'une quelconque des revendications 1 à 8, caractérisé en ce qu'il

|     |  |              |
|-----|--|--------------|
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|     | comprend en outre un substrat (14) supportant la-<br>dite masse de matériau extra-dur.   |              |
| 10. | Elément de coupe (10') suivant l'une quelconque<br>des revendications précédentes, caractérisé en ce<br>que ladite masse de matériau extra-dur comprend<br>des segments latéralement adjacents de matériau<br>extra-dur.   | 5            |
| 11. | Elément de coupe (10') suivant la revendication 10,<br>caractérisé en ce que ledit élément de coupe (10')<br>comprend une lame.  | 10           |
| 12. | Elément de coupe (10') suivant l'une quelconque<br>des revendications précédentes, caractérisé en ce<br>que ladite face de coupe (40) comporte une arête<br>de coupe périphérique (42), dont au moins une par-<br>tie a été polie jusqu'à un fini de surface d'une rugo-<br>sité de pratiquement 254 nm (10 micropouces) ou<br>moins.  | 15<br><br>20 |
| 13. | Elément de coupe (10') suivant la revendication 12,<br>caractérisé en ce que le fini de surface de ladite par-<br>tie d'arête de coupe périphérique a une rugosité de<br>50,8 nm (2 micropouces) ou moins.   | 25           |
| 14. | Elément de coupe (10') suivant la revendication 13,<br>caractérisé en ce que le fini de surface de ladite par-<br>tie d'arête de coupe périphérique a une rugosité de<br>12,7 nm (0,5 micropouce) ou moins.  | 30           |
| 15. | Elément de coupe (10') suivant l'une quelconque<br>des revendications 12 à 14, caractérisé en ce que<br>la partie polie de l'arête de coupe (42) a été polie<br>par rodage, usinage par faisceau d'ions ou polissa-<br>ge chimique.  | 35           |
| 16. | Elément de coupe (10') suivant la revendication 15,<br>caractérisé en ce que la partie polie de l'arête de<br>coupe (42) a été polie par rodage.   | 40           |
| 17. | Elément de coupe (10') suivant l'une quelconque<br>des revendications précédentes, caractérisé en ce<br>que ladite face de coupe (40) possède une arête de<br>coupe périphérique (42) ayant un chanfrein (24),<br>dont au moins une partie a été polie jusqu'à un fini<br>de surface d'une rugosité substantielle de 254 nm<br>(10 micropouces) ou moins.  | 45           |
| 18. | Elément de coupe (10') suivant la revendication 17,<br>caractérisé en ce que le fini de surface de ladite par-<br>tie de chanfrein a une rugosité de 50,8 nm (2 micro-<br>pouces) ou moins.  | 50           |
| 19. | Elément de coupe (10') suivant la revendication 18,<br>caractérisé en ce que le fini de surface de ladite par-<br>tie de chanfrein a une rugosité de 12,7 nm (0,5 mi-<br>cropouce) ou moins.   | 55           |
| 20. | Elément de coupe (10') suivant l'une quelconque<br>des revendications 17 à 19, caractérisé en ce que<br>la partie polie du chanfrein (24) a été polie par ro-<br>dage, usinage par faisceau d'ions ou polissage chi-<br>mique.   |              |
| 21. | Elément de coupe (10') suivant la revendication 20,<br>caractérisé en ce que la partie polie du chanfrein<br>(24) a été polie par rodage.  |              |
| 22. | Trépan à lames rotatif (30) pour le forage de forma-<br>tions souterraines, comprenant :   |              |
|     | - un corps de trépan (32) ayant une tige (34) qui<br>y est fixée pour relier ledit trépan à lames rotatif<br>(30) à un train de tiges,<br>- une face sur ledit corps de trépan (32),<br>- une pluralité d'éléments de coupe extra-durs<br>(10) disposés sur ladite face de corps de tré-<br>pan,   |              |
|     | caractérisé en ce qu'au moins un desdits élé-<br>ments de coupe extra-durs (10) est un élément de<br>coupe (10') suivant l'une quelconque des revendi-<br>cations 1 à 21.  |              |
| 23. | Procédé de fabrication d'un élément de coupe ex-<br>tra-dur (10') pour le forage de formations souterrai-<br>nes, ledit élément de coupe (10') comprenant une<br>masse de matériau extra-dur définissant une face<br>de coupe (40) pratiquement plane, caractérisé en<br>ce que le procédé comprend le polissage d'au<br>moins une partie (140) de ladite face de coupe (40)<br>jusqu'à un fini de surface d'une rugosité de prati-<br>quement 254 nm (10 micropouces) ou moins. |              |
| 24. | Procédé suivant la revendication 23, caractérisé en<br>ce qu'il comprend le polissage d'au moins une par-<br>tie (140) de ladite face de coupe (40) jusqu'à un fini<br>de surface d'une rugosité de pratiquement 50,8 nm<br>(2 micropouces) ou moins.  |              |
| 25. | Procédé suivant la revendication 24, caractérisé en<br>ce qu'il comprend le polissage d'au moins une par-<br>tie (140) de ladite face de coupe (40) jusqu'à un fini<br>de surface d'une rugosité de pratiquement 12,7 nm<br>(0,5 micropouce) ou moins.   |              |
| 26. | Procédé suivant l'une quelconque des revendica-<br>tions 23 à 25, caractérisé en ce que le polissage<br>d'au moins la partie (140) de la face de coupe est<br>effectué par rodage, usinage par faisceau d'ions ou<br>polissage chimique.   |              |
| 27. | Procédé suivant la revendication 26, caractérisé en<br>ce que le polissage d'au moins la partie (140) de la<br>face de coupe est effectué par rodage.  |              |

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28. Procédé pour modifier les caractéristiques de coupe d'un élément de coupe (10) à utiliser sur un trépan (30) pour le forage de formations souterraines, ledit élément de coupe (10) possédant une face de coupe extra-dure (40) ayant une rugosité de surface supérieure à 508 nm (20 micropouces), comprenant le rodage d'au moins une partie (140) de ladite face de coupe (40) de manière telle à réduire ladite rugosité de surface d'au moins cinquante pour-cent.
29. Procédé suivant l'une quelconque des revendications 27 et 28, caractérisé en ce qu'il comprend le rodage d'au moins la partie (140) de ladite face de coupe (40) avec des particules de diamant de plus en plus fines.
30. Procédé pour le forage de formations souterraines au moyen d'un trépan rotatif, caractérisé en ce que le trépan rotatif est un trépan tel que défini dans la revendication 22.

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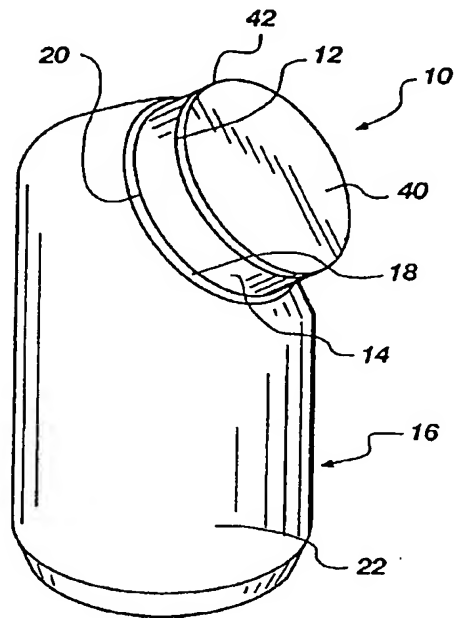


Fig. 1

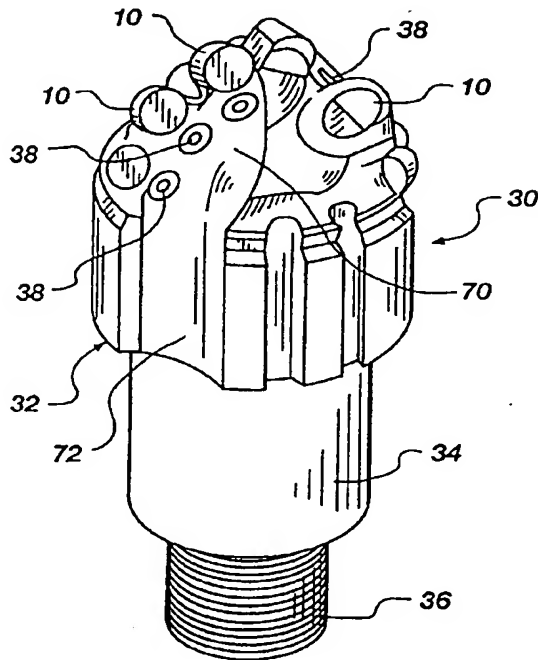


Fig. 2

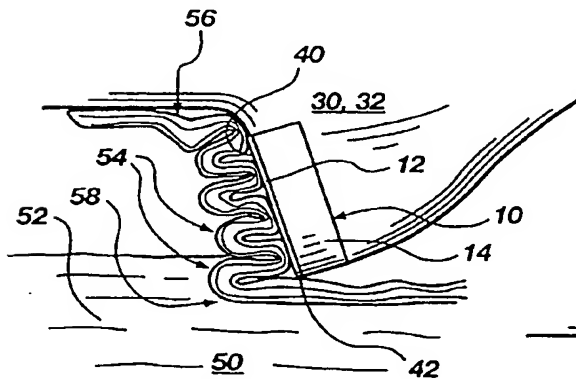


Fig. 3

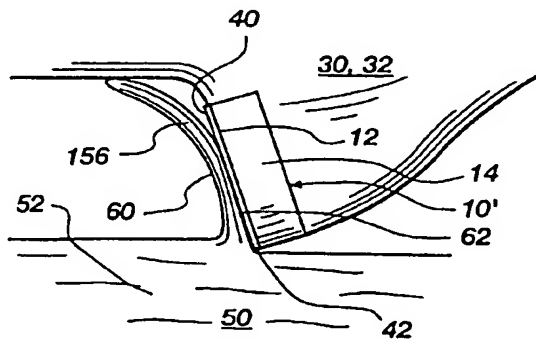


Fig. 4

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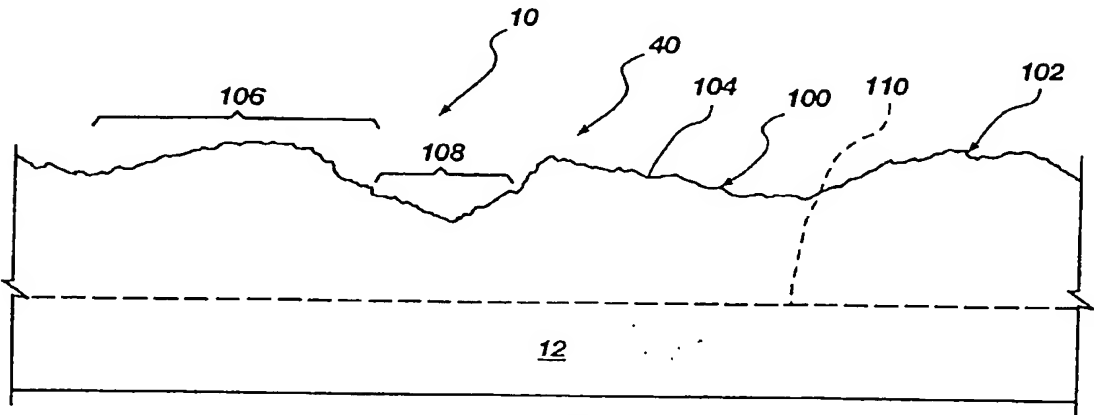


Fig. 5A

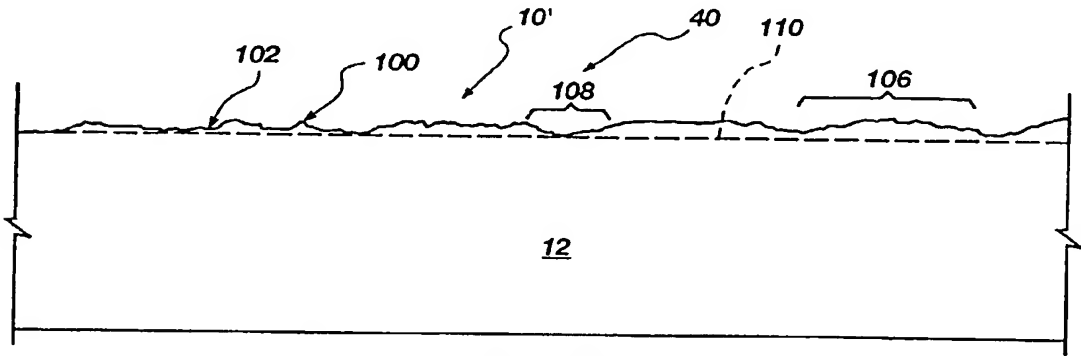


Fig. 5B

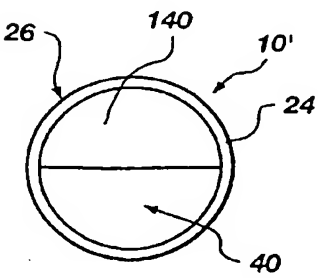


Fig. 6A

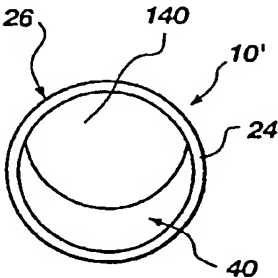


Fig. 6B

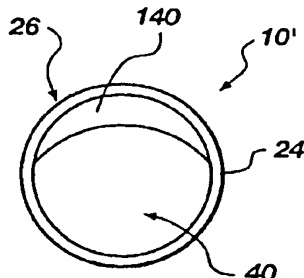
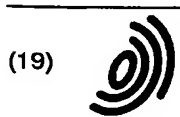


Fig. 6C



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(11) **EP 0 656 458 A3**

(12) **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:  
06.11.1996 Bulletin 1996/45

(51) Int. Cl.<sup>6</sup>: **E21B 10/56**, B23B 27/14,  
B24B 3/60, B24B 37/00

(43) Date of publication A2:  
07.06.1995 Bulletin 1995/23

(21) Application number: **94870183.4**

(22) Date of filing: **22.11.1994**

(84) Designated Contracting States:  
**BE DE DK FR GB IT NL**

(30) Priority: **22.11.1993 US 156086**

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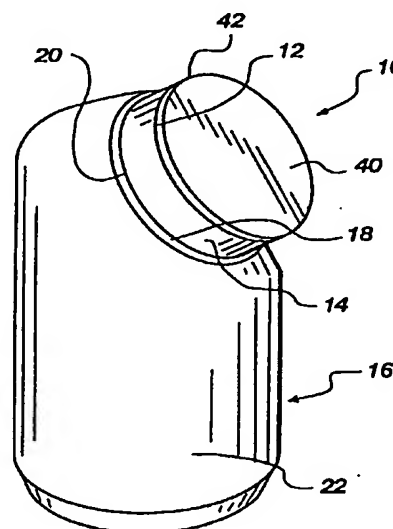
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(54) **Superhard cutting element having reduced surface roughness**

(57) A superhard cutting element (10) having a polished, low friction substantially planar cutting face (40) with a surface finish roughness of 254 nm (10  $\mu$  in.) or less and preferably 12,7 nm (0,5  $\mu$  in.) or less.



**Fig. 1**

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European Patent  
Office

## EUROPEAN SEARCH REPORT

Application Number  
EP 94 87 0183

| DOCUMENTS CONSIDERED TO BE RELEVANT   |  |   |   |
|---|--|---|---|
| Category  | Citation of document with indication, where appropriate, of relevant passages  | Relevant to claim   | CLASSIFICATION OF THE APPLICATION (Int.Cl.6)    |
| X   | EP-A-0 541 071 (SUMIMOTO ELECTRIC INDUSTRIES LIMITED)<br><br>* page 18 *<br>* page 6, line 30 - line 37 *<br>* abstract *                                | 1,2,<br>4-10,<br>14-23  | E21B10/56<br>B23B27/14<br>B24B3/60<br>B24B37/00 |
| A   |  | 11  |   |
| A   | * page 4, line 1 - line 2 *<br>---   | 24-29   |   |
| X   | EP-A-0 480 394 (SUMIMOTO ELECTRIC INDUSTRIES LIMITED)<br><br>* page 12 *<br>* abstract *<br>* column 4, line 42 - line 44 *                              | 1,2,<br>4-10,<br>14-23  |   |
| A   |  | 11  |   |
| A   | * page 2, line 21 - line 26 *<br>---   | 24-29   |   |
| X   | EP-A-0 298 729 (SUMIMOTO ELECTRIC INDUSTRIES LIMITED)<br><br>* abstract *<br>* page 3, line 53 *<br>* page 5; table 1 *<br>* page 3, line 35 - line 44 * | 1,2,<br>4-10,<br>14-23  |   |
| A   |  | 11  |   |
| Y   | * page 4, line 18 - line 21 *<br>---   | 24-29   |   |
| Y   | US-A-5 184 433 (MAACK)<br>* column 2, line 50 - line 53 *<br>---   | 24-29   |   |
| A   | US-A-4 693 035 (DOYLE)<br>* column 1, line 19 - line 26 *<br>---   | 24-29   |   |
| A,D   | US-A-4 976 324 (TIBBITS)<br><br>* column 3, line 40 - line 44; claim 1 *<br>---<br>-/--  | 1,11,14,<br>22  |   |
| The present search report has been drawn up for all claims  |  |   |   |
| Place of search<br>THE HAGUE  |  | Date of completion of the search<br>13 September 1996   | Examiner<br>Sogno, M                            |
| CATEGORY OF CITED DOCUMENTS   |  | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>.....<br>& : member of the same patent family, corresponding document |   |
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EPO FORM 1503 (02.92) (P4/C01)

EP 0 656 458 A3



European Patent  
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## EUROPEAN SEARCH REPORT

Application Number  
EP 94 87 0183

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|--|--|---|--|
| Category   | Citation of document with indication, where appropriate, of relevant passages                        | Relevant to claim                                     | CLASSIFICATION OF THE APPLICATION (Int.Cl.6) |
| A  | US-A-4 539 018 (WHANGER)<br>* column 5, line 4 - line 11 *<br>* column 4, line 37 - line 46 *<br>--- | 1,11,14,22  |  |
| A  | EP-A-0 149 530 (CDP, LIMITED)<br>* claim 31 *<br>---   | 1,11,14,22  |  |
| A  | US-A-4 211 508 (DILL)<br>* abstract *<br>* claim 1 *<br>---  | 1,11,14,22  |  |
| A  | US-A-5 011 509 (FRUSHOUR)<br>* claim 2 *<br>---  | 1,11,14,22  |  |
| A  | DE-A-42 40 053 (AGATHON AG MASCHINENFABRIK)<br>* the whole document *<br>---                         | 24-29   |  |
| A  | DE-A-41 41 900 (VOLLMER WERKE MASCHINENFABRIK GMBH)<br>* the whole document *<br>---                 | 24-29   |  |
| A  | US-A-5 215 415 (FUKUOKA)<br>* column 5, line 61 - line 66 *<br>-----                                 | 24-29   | TECHNICAL FIELDS SEARCHED (Int.Cl.6)         |
| The present search report has been drawn up for all claims   |  |   |  |
| Place of search<br>THE HAGUE   |  | Date of completion of the search<br>13 September 1996 | Examiner<br>Sogno, M                         |
| <p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone<br/>Y : particularly relevant if combined with another document of the same category<br/>A : technological background<br/>O : non-written disclosure<br/>P : intermediate document</p> <p>T : theory or principle underlying the invention<br/>E : earlier patent document, but published on, or after the filing date<br/>D : document cited in the application<br/>L : document cited for other reasons<br/>.....<br/>&amp; : member of the same patent family, corresponding document</p> |  |   |  |

EPO FORM 150 (01.82) (P4/COL)